Does predation by the fish *Gambusia holbrooki* (Atheriniformes: Poeciliidae) contribute to declining frog populations?

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ABSTRACT

Gambusia holbrooki is a small, aggressive fish introduced into Australia in 1925 to control mosquitoes. It has been suggested that this species may also prey on tadpoles and be a contributing factor in the decline of some Australian frog populations. We examined the influence of tadpole body size (10 mm, 15 mm and 20 mm), predator prey ratio (1:1, 1:2 and 1:4) and nutritional status of the predator on the level of predation by *G. holbrooki* on tadpoles of *Limnodynastes peronii*. Unfed fish attacked all three size classes of tadpoles without any significant preference but did so more vigorously when the predator/prey ratio was densest. Predator/prey ratio had no significant overall effect on attack of tadpoles by fed fish but there was a preference for the smaller tadpoles during the first six hours of the experiment. Unfed fish also consumed more of the tadpoles they attacked than did the fed fish.

Field surveys were carried out on 10 permanent water bodies in north-west Sydney to examine any correlation between the abundance of *G. holbrooki* and frog species richness or abundance. The most abundant species was *C. signifera*. Regression analysis showed a negative relationship between density of *G. holbrooki* and the abundance of frogs. A positive relationship between the abundance of tree frog species and the cover of aquatic vegetation was also found. While this study did not investigate other factors contributing to declining frog populations, the results of the laboratory experiments and field surveys are consistent with the hypothesis that *G. holbrooki* is contributing to declining frog populations.

INTRODUCTION

A decline in frog populations has been reported across all continents of the world, including Australia (Blaustein and Wake 1990; Baringa 1990; Martin 1990; Ferraro and Burgin 1993). Of Australia's 203 species of frogs, approximately 10% are suspected to be now extinct (Phillips 1990) and at least 34 species are considered endangered (Tyler 1994). On a global scale, a range of factors have been suggested as possible causes for this decline. These include climate change, habitat degradation and ozone layer depletion (Jutterbuck 1990). On a local scale there have been examples of increased mortality due to insecticide use (Tyler 1991), altered water flow regimes (Hero 1991), reduced water quality (Beattie and Tyler-Jones 1992; Warner *et al.* 1993), habitat disturbance (Tyler and Davis 1985; Barinaga 1990) and the introduction of exotic flora and fauna (Bradford 1989; Blaustein and Wake 1990; Bronmark and Edenhamn 1994). In this latter category, it has been suggested that introduced fish may influence the survivorship of frogs by preying on their eggs and larvae (Grubb 1990; Ferraro and Burgin 1993).

For gape-limited fish predators, prey body size has a significant influence on the level of predation (Semlitsch and Gibbons 1988). Some species of amphibians have developed characteristics that reduce their vulnerability to predation; such as, unpalatability, reduced activity, and selection of fish-free ponds for breeding (Grubb 1972; Smith 1983; Crump 1984; Kats *et al.* 1988; Petranka 1989; Resetarits *et al.* 1989).

Gambusia holbrooki (previously *G. affinis*) is a member of the Poeciliidae family. It is commonly called the Mosquito Fish because of its reputation as a biological control for pest mosquitoes. A native of South America, *G. holbrooki* was introduced to Sydney's waterways in 1925 following concern over the transmission of mosquito-borne diseases (Myers 1965). *Gambusia holbrooki* quickly adapted to the Australian waterways and presently occupies permanent waterways in all major geographical areas of Australia (Merrick and Schmida 1984). It has become so abundant in some areas that it is now considered a pest (Allen 1989). Mosquito Fish tolerate a broad range of environmental conditions, can exist in high densities and have a non-specific diet. Their high fecundity, viviparity and low fry mortality result in rapid population growth (Moyle and Cech 1982).

Hurlbert *et al.* (1972) have suggested that *G. holbrooki* introduced to non-native sites adversely affects the aquatic environment by altering invertebrate and phytoplankton communities. It may also reduce native fish populations through predation of eggs and fry as well as competitive interaction with adults (Leger Moss 1988). Lloyd (1989) has proposed that 35 fish species worldwide are in decline due to predation by *G. holbrooki.*

In pristine environments, *G. holbrooki* may be controlled by inter-specific competition with native species such as the ornate Rainbow Fish *Rhadinocentrus ornatus* (Leger Moss 1988). However, Lloyd (1989) reported that Mosquito Fish gain ascendancy when streams become degraded. Native fish are much less tolerant of polluted water, and are unable to outcompete *G. holbrooki* in degraded habitats.

Although *G. holbrooki* is primarily insectivorous (McDowall 1980; Booth 1980), it is very aggressive and may attack and prey upon tadpoles (Ferraro and Burgin 1993; Mahony 1993). Information regarding predation by *G. holbrooki* upon tadpoles is mainly anecdotal but its predation of amphibian spawn has been documented (Grubb 1972). Knowledge of the factors influencing predation are important prerequisites for the development of appropriate conservation strategies (Bronmark and Edenhamn 1994).

This study investigated whether *G. holbrooki* could be contributing to the decline in native frog populations. Of particular interest was to identify the factors influencing the level of *G. holbrooki* predation on tadpoles and the influence of the presence of *G. holbrooki* on the composition of anuran pond communities. This study did not investigate other factors contributing to frog population decline or how such other factors may interact with predation by *G. holbrooki.*

MATERIALS AND METHODS

Experimental Animals

Gambusia holbrooki was collected from the Macquarie University Dam. Only those in the size range 25–35 mm SL were used in order to restrict the influence of predator body size on the predation experiments.

The Striped Marsh Frog *Limnodynastes peronii* is a relatively large frog reaching 65–70 mm in length and it is common in the coastal regions of eastern Australia (Tyler 1992). The tadpoles of *L. peronii* used in the predation experiments were raised from a single egg mass collected from the lungfish ponds at Macquarie University. The Common Brown Froglet *Crinia signifera* is a small frog reaching 35 mm in length and is widely distributed throughout southeastern Australia (Tyler 1992). Tadpoles of *C. signifera* used in predation experiments were collected from the Lungfish ponds with a 400 mm diameter dip net.

The tadpoles of each species were maintained in tanks under conditions similar to the experimental tanks and were regularly fed boiled lettuce and commercial fish-food flakes.

Predation Experiments

Limnodynastes peronii tadpoles of 10 mm, 15 mm and 20 mm SV length were tested with a predator/prey ratio of 1:2 (5 fish and 10 tadpoles). Three predator/prey ratios, 1:1 (10 fish and 10 tadpoles), 1:2 and 1:4 (5 fish and 20 tadpoles) were tested with *L. peronii* tadpoles of 15 mm SV length. *Crinia signifera* tadpoles of 10 mm SV length were tested at a predator/prey ratio of 1:2.

For each experimental trial, ten tanks (600 × 300 × 260 mm) were used with 15 litres of aged water and a 20–30 mm depth substrate of medium-coarse gravel. The tanks were not provided with filtration or aeration and after each trial they were cleaned and the water changed.

The fish were introduced to the experimental tanks 48 hours before each trial. In five of the tanks, the fish were fed 4 hours prior to introduction of the tadpoles while the fish in the other five tanks were not fed during the 48 hours prior to the trials. Each trial commenced mid-morning. Tadpoles were released into each tank simultaneously and were not provided with food during the trial.

The number of tadpoles either lethally attacked or consumed were recorded after 10 minutes, 60 minutes, 6 hours, and 24 hours. Predation was defined as death of the tadpole resulting from lethal attack by *G. holbrooki*, or as consumption, when all traces of the tadpole had gone from the tank. Both values were recorded as a percentage of total tadpoles released into each tank at the beginning of each trial. No tadpole was removed from the tank until 24 hours had elapsed. After 24 hours all remaining tadpoles and fish were removed from the tank. These tadpoles and fish were not used in subsequent experiments.

A two fixed factor analysis of variance was used to analyse the results of the predation experiments. The assumption of homogeneity was evaluated using Cochran's test.

Field Surveys

Site descriptions

Ten ponds were selected in the northwestern region of Sydney and surveyed over the period September-October, 1994:

Pond A: Macquarie University Dam (33°46'30"S, 151°06'90"E). A lake created by the damming of Mars Creek in 1991. There is little tree cover by the side of the pond but upslope of the northern bank is a small area of woodland.

The bulrushes are regularly cut-back and following periods of heavy rain there is a significant input of storm water.

Pond B: Top Lungfish Pond (33°46'10"S, 151°06'70"E), and,

Pond C: Bottom Lungfish Pond (33°46'10"S, 151°06'70"E). Ponds B and C were approximately two-years old at the time of sampling. Each has a capacity of 750 m^3. Both were covered with netting to inhibit entry by birds during the course of this study. The top pond contained nine adult lungfish and an unknown number of juveniles.

Pond D: Top Tondall Dam (33°37'90"S, 150°58'30"E). A dam approximately 6 years old with some tree cover.

Pond E: Bottom Tondall Dam (33°37'60"S, 150°58'30"E). The pond was created by damming a small creek more than six years ago. The pond is at the bottom of a gully surrounded by eucalypt woodland.

Pond F: API Country Club (33°41'30"S, 150°55'30"E). A dam situated in a golf course with no tree cover, and an adjacent, recently constructed dam.

Pond G: Castlebrook Gardens Dam (33°41'30"S, 150°55'30"E). A dam with a small island in the middle. There is a small stream emptying into the dam which was barely running at the time of study. Some portions of the pond bank have been covered with concrete.

Pond H: Market Dam (33°43'30"S, 150°56'30"E). A dam adjacent to Caddies Creek. There is no emergent aquatic vegetation and the bank is lined with *Casuarina* spp.

Pond I: Top Parklea Dam (33°44'30"S, 150°56'60"E). A dam used for irrigation of the adjacent sports fields. The western boundary is bordered by farms.

Pond J: Bottom Parklea Dam (33°44'30"S, 150°56'60"E). A semi-natural water body situated at the bottom of a small gully. This pond is in a grazing paddock so there were some cattle present and a few overhanging trees. There is a similar-sized dam to the west with less aquatic vegetation.

The percentage cover of water body circumference by aquatic vegetation was recorded for each pond and identification of aquatic plants was carried out using Sainty and Jacobs (1981), Beadle *et al.* (1982) and Robinson (1991).

Estimating Gambusia holbrooki *densities*

Each site was inspected twice for *G. holbrooki* using a visual abundance classification based on the spatial distribution of the fish throughout the pond. Their density was estimated by taking 10 random sweeps in each pond. The data were then averaged to obtain a relative measure of density (number of *G. holbrooki* per sweep per site). Although this technique did not yield an estimate of total abundance at each site it did give a measure of comparison among the 10 ponds.

Estimating frog populations

Frogs were either identified morphologically using Robinson (1993), with further reference to Tyler (1994) or by their calls using Grigg and Barker (1983). Since frequency, duration and pattern of calls act as isolating mechanisms between sympatric species (Tyler 1994), they are a good means of taxonomic identification (Littlejohn 1968).

Although gathering richness (number of species) data is relatively simple for frogs, quantifying their abundance is more difficult (Slater 1978). Southwood (1966) suggested that catch per unit effort in a particular habitat provides a good estimate of the actual population. A modification of this method as described by Ferraro (1993) was used. The perimeter of each pond was searched on three occasions, at night for one hour, twice following rain and once following 10 nights without rain. For each replicate search all ponds were visited within three days of each other to minimize variation due to weather conditions.

The number of individuals identified during the three visits was averaged to obtain a relative measure of abundance (number of frogs per hour search). Regression analysis was used to determine the relationships between the frog population size and the abundance of *G. holbrooki* and the per cent cover of aquatic vegetation.

RESULTS

Predation Experiments

The mean per cent mortality of the three body size classes of *L. peronii* tadpoles exposed to *G. holbrooki* over four consecutive time periods is shown in Figure 1. Fed fish attacked only 10 mm tadpoles over the first hour and 20 mm tadpoles were attacked only during the 6–24 hour period (Fig. 1a). Unfed fish readily attacked all the three size classes of tadpoles presented over the experimental period (Fig. 1b). After 10 minutes, there was a significant difference in the mean percent mortality of tadpoles between the dietary status of the fish ($F_{1,24} = 6.75$, $P = 0.02$) and the body size of the tadpoles ($F_{2,24} = 6.30$, $P = 0.01$). After 24 hours, however, there was a significant difference due to dietary status ($F_{1,24} = 22.53$, $P < 0.01$) but not to tadpole body size ($F_{2,24} = 2.27$, $P = 0.125$).

The mean per cent mortality of *L. peronii* tadpoles exposed to *G. holbrooki* at three predator:prey ratios over four consecutive time periods is shown in Figure 2. Both unfed and

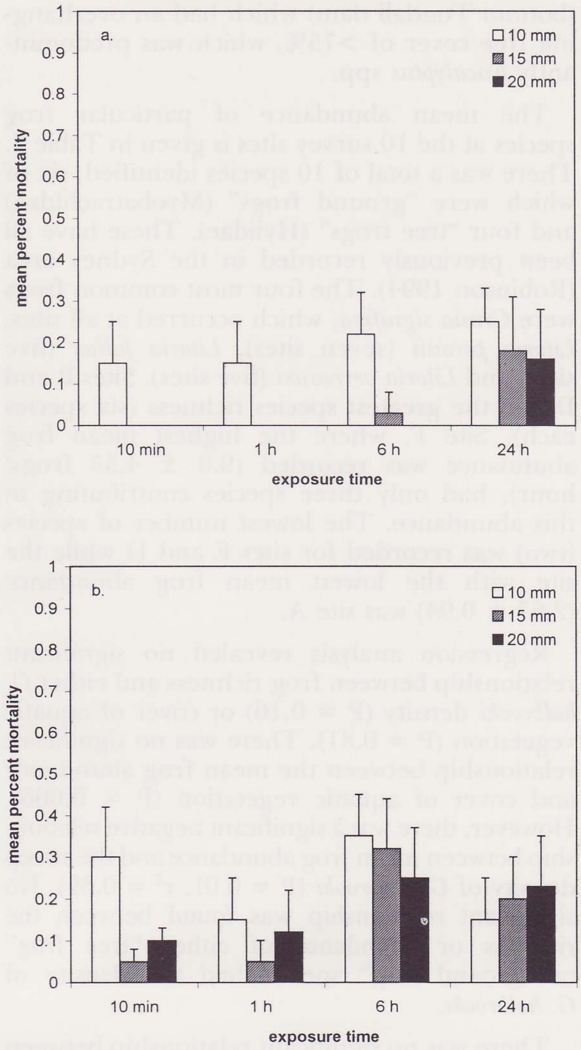

Figure 1. The mean per cent mortality (± st. dev) of *Limnodynastes peronii* tadpoles (body size 10, 15 and 20 mm SVL) when exposed to (a) fed and (b) unfed *Gambusia holbrooki* (predator:prey = 1:2) over four consecutive time periods.

fed fish attacked tadpoles at the three predator:prey ratios over all time periods. After 10 minutes there was a significant difference in the mean per cent mortality of tadpoles between the dietary status of the fish ($F_{1,24} = 18.44$, $P < 0.01$) and predator:prey ratio ($F_{2,24} = 9.75$, $P < 0.01$). The highest mean per cent mortality of tadpoles (80%) occurred during the first ten minutes, by unfed fish at a predator:prey ratio of 1:1. After 24 hours there was a significant difference in mean per cent mortality between the dietary status of the fish ($F_{1,24} = 20.13$, $P < 0.01$) but not to predator:prey ratio ($F_{2,24} = 3.18$, $P = 0.06$).

After 24 hours, there was a significant difference in the mean per cent of *L. peronii* tadpoles consumed by *G. holbrooki* between tadpole body size ($F_{2,24} = 40.32$, $P < 0.01$). A greater number of the smallest tadpoles were consumed at predator:prey ratio 1:2. There was also a significant difference in the mean percent of tadpoles consumed between predator:prey ratio ($F_{2,24} = 6.74$, $P = 0.01$), more tadpoles were consumed at predator:prey ratio 1:1 than either 1:2 or 1:4. Unfed fish consumed a significantly greater proportion of tadpoles regardless of tadpole body size ($F_{1,24} = 27.08$, $P < 0.01$) or predator:prey ratio ($F_{2,24} = 28.26$, $P < 0.01$) than fed fish.

The mean per cent mortality of *L. peronii* and *C. signifera* tadpoles (body size 10 mm) exposed to *G. holbrooki* (predator:prey ratio 1:2) is shown in Figure 3. After 10 minutes, there was a significant difference in the mean per cent mortality of tadpoles between the dietary status of fish ($F_{1,16} = 10.32$, $P = 0.01$) but not the tadpole species ($F_{1,16} = 2.74$, $P = 0.117$). However, after 24 hours, there was a significant difference in mean per cent mortality between the dietary status of the fish ($F_{1,16} = 7.78$, $P = 0.01$) but not tadpole species ($F_{1,16} = 0.98$, $P = 0.34$). However, due to the substantial variance in the data (Cochran's Test = 0.89, $P < 0.01$), these results should be approached with caution.

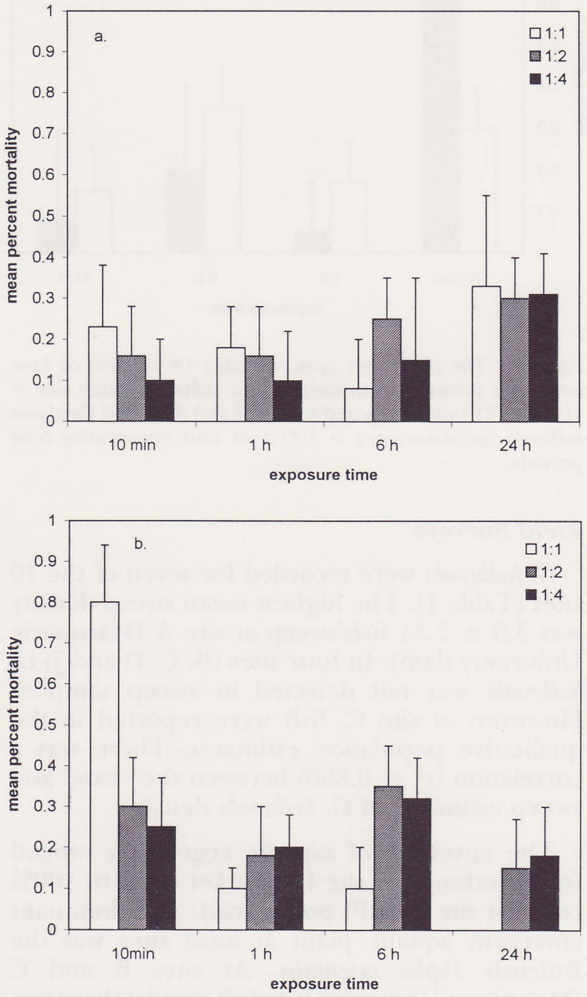

Figure 2. The mean per cent mortality (± st. dev) of *Limnodynastes peronii* tadpoles (body size = 10 mm SVL) when exposed to (a) fed and (b) unfed *Gambusia holbrooki* (predator:prey 1:1, 1:2 and 1:4) over four consecutive time periods.

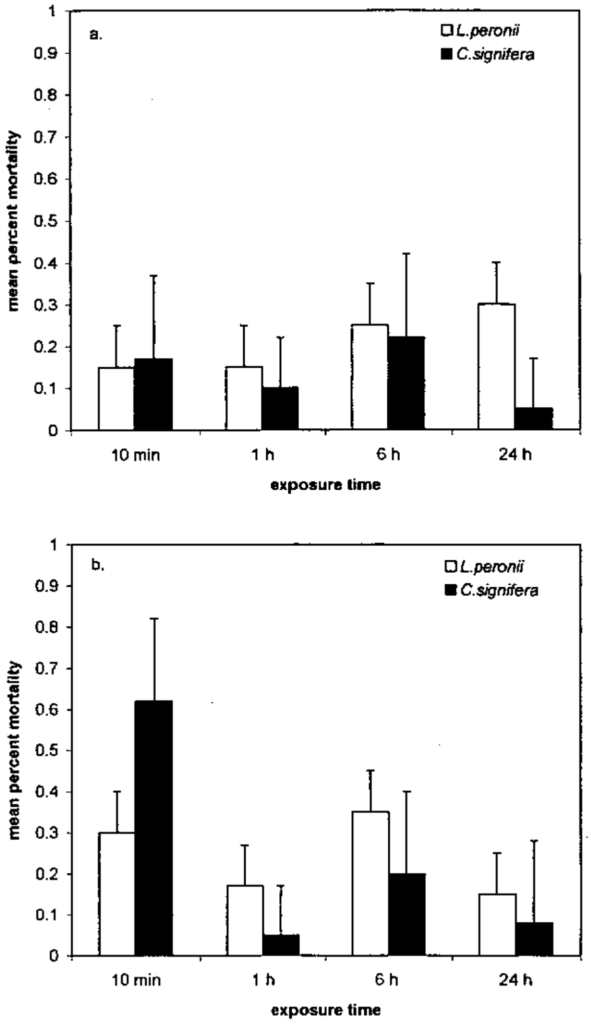

Figure 3. The mean per cent mortality (± st. dev) of *Limnodynastes peronii* and *Crinia signifera* tadpoles (body size = 10 mm SVL) when exposed to (a) fed and (b) unfed *Gambusia holbrooki* (predator:prey = 1:2) over four consecutive time periods.

Field Surveys

G. holbrooki were recorded for seven of the 10 sites (Table 1). The highest mean sweep density was 3.9 ± 2.34 fish/sweep at site A (Macquarie University dam). In four sites (B, C, D and J) *G. holbrooki* was not detected in sweep samples. However, at site C, fish were reported in the qualitative population estimates. There was a correlation ($r^2 = 0.856$) between the visual and sweep estimates of *G. holbrooki* density.

The coverage of aquatic vegetation ranged from nothing for site H (Market dam) to 100% cover at site G (API golfcourse). The dominant emergent aquatic plant at most sites was the Bulrush *Typha orientalis*. At sites B and C (Macquarie University lungfish ponds) there was a good cover of Water Hyacinth *Eichornia crassipes*. The majority of the sites had very few overhanging trees since they were located on farming properties. The exception was site E (bottom Tondall dam) which had an overhanging tree cover of >75%, which was predominantly *Eucalyptus* spp.

The mean abundance of particular frog species at the 10 survey sites is given in Table 2. There was a total of 10 species identified, six of which were "ground frogs" (Myobatrachidae) and four "tree frogs" (Hylidae). These have all been previously recorded in the Sydney area (Robinson 1994). The four most common frogs were *Crinia signifera*, which occurred at all sites, *Litoria peronii* (seven sites), *Litoria fallax* (five sites) and *Litoria verreauxi* (five sites). Sites B and D had the greatest species richness (six species each). Site F, where the highest mean frog abundance was recorded (9.0 ± 4.55 frogs/hour), had only three species contributing to this abundance. The lowest number of species (two) was recorded for sites E and H while the site with the lowest mean frog abundance (2.67 ± 0.94) was site A.

Regression analysis revealed no significant relationship between frog richness and either *G. holbrooki* density ($P = 0.16$) or cover of aquatic vegetation ($P = 0.81$). There was no significant relationship between the mean frog abundance and cover of aquatic vegetation ($P = 0.065$). However, there was a significant negative relationship between mean frog abundance and the sweep density of *G. holbrooki* ($P = 0.01$, $r^2 = 0.59$). No significant relationship was found between the richness or abundance of either "tree frog" or "ground frog" species and the density of *G. holbrooki*.

There was no significant relationship between the abundance of "ground frogs" and the cover of aquatic vegetation ($P = 0.12$). However, there was a significant positive relationship between the abundance of "tree frog" species and the per cent cover of emergent aquatic vegetation ($P = 0.03$, $r^2 = 0.49$).

DISCUSSION

The aim of this study was to determine whether predation by *Gambusia holbrooki* could be contributing to declining frog populations. Therefore, the most important finding from the laboratory experiments was that *G. holbrooki* will attack and kill tadpoles. *Gambusia holbrooki* is well documented as an insectivorous predator (Booth 1980; Merrick and Schmida 1984; Lloyd *et al.* 1986) but the results described here suggest that *G. holbrooki* is also likely to be a predator of tadpoles.

Since unfed *G. holbrooki* preyed more heavily on tadpoles than did fed fish, tadpoles in disturbed habitats, where insects are less available, may be more susceptible to predation. *G. holbrooki* is commonly found in disturbed habitats because it is relatively tolerant to

Table 1. Qualitative (visual abundance; 1 = absent, 2 = sparse, 3 = common, 4 = abundant and 5 = very abundant) and quantitative (mean number of fish per sweep from 10 replicate sweeps) estimates of *Gambusia holbrooki* density and per cent cover of emergent, aquatic vegetation at the 10 survey ponds.

	Survey Ponds									
Variables	A	B	C	D	E	F	G	H	I	J
G. holbrooki										
qualitative estimate	5	1	2	1	2	4	4	5	3	1
mean sweep density (st. dev)	3.9(2.34)	0.0(0.0)	0.0(0.0)	0.0(0.0)	0.3(0.64)	1.1(1.13)	0.8(1.24)	2.3(2.05)	1.2(1.60)	0.0(0.0)
Emergent aquatic vegetation per cent cover	60	30	10	10	20	70	100	0	10	90

Table 2. The mean abundance (per hour search) of each frog species, the frog richness (number of species) and the mean total frog abundance (± st. dev) from three sampling periods at the 10n survey ponds. A (+) indicates a species was recorded calling from a pond but no individuals were collected during any search.

		Survey Ponds									
Species	Common Name	A	B	C	D	E	F	G	H	I	J
Family: Myobatrachidae											
Crinia haswelli	Haswell's Froglet				2.33	1.00					
Crina signifera	Brown Froglet	1.67	4.33	3.33	2.66	3.66	2.66	2.00	2.66	3.33	3.00
Limnodynastes peronii	Striped Marsh Frog	0.66	3.33	3.33							
Limnodynastes tasmaniensis	Spotted Marsh Frog			+							
Pseudophryne bibroni	Bibron's Toadlet		+								
Uperolea laevigata	Smooth Toadlet	0.33	0.33		1.00						
Family: Hylidae											
Litoria dentata	Bleating Tree Frog		+								
Litoria fallax	Dwarf Tree Frog				0.33		3.33	1.66		2.00	2.66
Litoria peronii	Peron's Tree Frog		0.66	1.33	1.33		3.00	1.00		0.33	0.66
Litoria verreauxi	Verreaux's Frog				0.66			+	1.33	0.33	1.66
Species richness		3	6	4	6	2	3	4	2	4	4
Mean total frog abundance (st. dev)		2.67(0.94)	8.67(1.25)	8.00(0.00)	8.30(3.30)	4.67(1.25)	9.00(4.55)	4.60(1.25)	4.00(0.82)	6.00(2.94)	8.00(2.16)

pollution (Lloyd *et al.* 1986) as are some of the more common species of tadpoles. The fact that the size of the tadpoles and the ratio of tadpoles to fish had little effect on the attacks made on tadpoles by hungry fish, suggests that *G. holbrooki* initially responds to hunger rather than aggression. This is supported by the work of Bence and Murdoch (1986), who also found that *G. holbrooki* responded to its own hunger level rather than prey density. Fed fish however, also attack tadpoles but not necessarily as food. Thus, even where preferable foods are in abundant supply, tadpoles may still be severely attacked by *G. holbrooki.*

Handling time is an important factor influencing size limited predation (Brodie and Formanowics 1983; Begon *et al.* 1990). *Gambusia holbrooki* can easily consume the 10 mm sized tadpoles, usually in one or two strikes, but a longer handling time is required for larger tadpoles. Previous research has shown small tadpoles to be more susceptible to predation by vertebrate (Morin 1981; Semlitsch and Gibbons 1988; Alford 1989; Petranka 1989; Semlitsch 1993) and invertebrate (Caldwell *et al.* 1980; Crump 1984; Travis *et al.* 1985; Richards and Bull 1990) predators. However, our results indicate small tadpoles were at no greater risk than larger tadpoles from predation during extended exposure to *G. holbrooki.*

Tadpoles are particularly susceptible to predation immediately following hatching when they hang vertically, immobile beneath the egg mass. During this time the tadpoles are small and are not able to actively avoid predation. In the case of *Limnodynastes peronii*, there may be more than 800 tadpoles suspended under one egg mass. Although these tadpoles are at risk from predation because of their small size, the results of the predator/prey ratio experiments suggest predation is initially significantly lower at higher prey densities. However, both tadpole body size and abundance will affect the level of predation since a single fish may consume a greater number of small tadpoles. Regardless of the density of *G. holbrooki* in a water body, tadpoles are likely to be exposed to predation at some time during their larval period.

Some tentative conclusions can be drawn from the field studies which suggest that the presence of *G. holbrooki* may directly affect the frog communities of permanent ponds. The presence of *G. holbrooki* did correlate with a lower abundance of frogs in general but appeared to have little, if any, affect on the composition of the frog community.

The richness of a pond's frog community will depend on the ability of the species to locate the waterbody and the presence of species in the local area. If *G. holbrooki* are altering the species composition of permanent ponds it would be presumably through selective predation of particular tadpole species. There have been no reports of direct predation of adults. During spawning, it is possible that frogs exhibit a preference for ponds without fish (Bronmark and Edenhamn 1994) but no specific studies have been undertaken to examine this proposition. If a species did exhibit a preference for a fish-free spawning habitat, then the presence of *G. holbrooki* could influence the abundance of that frog. Predation by *G. holbrooki* upon tadpoles could reduce the abundance of frogs by reducing the number reaching metamorphosis. The impact of *G. holbrooki* will depend on the abundance of tadpoles, the length of larval period and the susceptibility of the species.

Gambusia holbrooki are indicative of disturbed waterbodies. Although *G. holbrooki* could be reducing the abundance of frogs, there are other factors associated with disturbed habitats that may be of greater importance. There is a number of factors that could be influencing frog communities. Pollution due to suburban stormwater, disturbance of the aquatic and/or terrestrial vegetation or the presence of non-fish predators would influence frog populations.

Studies have indicated that pesticides and other chemicals can adversely affect frog populations (Ferraro and Burgin 1993). As reported in Ferraro and Burgin (1993) studies carried out by Johnson in 1976 found that the reaction of tadpoles to different herbicides and pesticides varied depending on the chemical concentration, frog species and tadpole age. A number of the survey sites were located in the proximity to agricultural areas, on which pesticides and/or herbicides are used. The leaching or runoff of these chemicals could alter community structure by reducing the abundance of sensitive species and/or indirectly increasing the inter-specific competition.

The natural variation that is found among ponds makes extrapolation of ecological conclusions difficult. Future studies should address a greater range of factors that may be influencing frog populations such as, pond area, pond vegetation, pond water pH, pesticide/herbicide concentration, distance from nearest permanent water body and number of ephemeral water bodies. A study of this kind could test the null hypothesis that the density of *G. holbrooki* does not have a significantly greater impact on frog populations than other biotic or abiotic factors.

For species that are particularly susceptible to *G. holbrooki,* the occurrence of ephemeral waterbodies surrounding permanent water bodies would be valuable refuge sites. *Gambusia holbrooki* and frogs could co-exist during periods of high rainfall due to the presence of ephemeral waterbodies. These water bodies provide a refuge from fish predation. For species shown to be preyed upon by *G. holbrooki*, provision of ephemeral sites will ensure maintenance of their population. Such pro-active actions are needed to forestall further declines in native frog populations.

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REFERENCES

Alford, R. A., 1989. Variation in predator phenology affects predator performance and prey community composition. *Ecology* **70:** 206–19.

Allen, G. R., 1989. *Freshwater Fishes of Australia.* T. F. H. Publications: Brookvale.

Barinaga, M., 1990. Where have all the froggies gone? *Science* **247:** 1034–034.

Beadle, N. C., 1982. *The vegetation of Australia.* Cambridge University Press: Sydney.

Beattie, R. C. and Tyler-Jones, R., 1992. The effect of low pH and aluminium on breeding success in the frog *Rana temporaria. J. Herpetol.* **26:** 353–60.

Begon, M., Harper, J. L. and Townsend, C. R., 1990. *Ecology: Individuals, populations and communities.* Blackwell Scientific Publications: Boston.

Bence, J. R. and Murdoch, W. W., 1986. Prey size selection by the mosquitofish: relation to optimal diet theory. *Ecology* **67:** 24–36.

Blaustein, A. R. and Wake, D. B., 1990. Declining Amphibian Populations: A Global Phenomenon? *TREE* **5:** 203–04.

Booth, D. J., 1980. Investigations into the extent and mechanisms of prey-size selection by the fish species *Pseudomugil signifer* (KNER) and *Gambusia affinis* (Baird and Girard). unpublished B. Sci (Hons) thesis. University of Sydney.

Bradford, D. F., 1989. Allotropic distribution of native frogs and introduced fishes in high Sierra Nevada Lakes of California: Implication of the negative effects of fish introductions. *Copeia* **1989**(3): 775–78.

Brodie, E. D., Formanowicz, D. R. and Jr., 1983. Prey size preference of predators: Differential vulnerability of larval anurans. *Herpetologica* **39:** 67–75.

Bronmark, C. and Edenhamn, P., 1994. Does the presence of fish affect the distribution of tree frogs *(Hyla arborea)*? *Conserv. Biol.* **8:** 841–45.

Caldwell, J. P., Thorp, J. H. and Jervey, T. O., 1980. Predator-prey relationships among larval dragonflies, salamanders and frogs. *Oecologia* **46:** 285–89.

Crump, M. L., 1984. Ontogenetic changes in vulnerability to predation in tadpoles of *Hyla pseudopuma. Herpetologica* **40**(3): 265–71.

Ferraro, T. J., 1993. Amphibian decline: a case study in western Sydney. Pp. 197–204 in *Herpetology in Australia: A Diverse Discipline* ed by D. Lunney and D. Ayers. Royal Zoological Society of New South Wales: Mosman.

Ferraro, T. J. and Burgin, S., 1993. Review of environmental factors influencing the decline of Australian frogs. Pp. 205–18 in *Herpetology in Australia: A Diverse Discipline* ed by D. Lunney and D. Ayers. Royal Zoological Society of New South Wales: Mosman.

Grigg, G. and Barker, J., 1983. *Frog Calls of S.E. Australia,* (Audio). Australian Museum: Sydney.

Grubb, J. C., 1972. Differential predation by *Gambusia affinis* on the eggs of seven species of anuran amphibians. *Amer. Midland Natur.* **88:** 102–08.

Hero, J., 1991. A froggy forecast. *Wildl. Aust.* **28:** 14–15.

Hurlbert, S. H., Zedler, J. and Fairbanks, D., 1972. Ecosystem alteration by mosquitofish *(Gambusia affinis)* predation. *Science* **175:** 639–41.

Jutterbuck, J. E., 1990. Comments about the amphibian decline symposium. *Herpetol. Rev.* **21:** 75–76.

Kats, L. B., Petranka, J. W. and Sih, A., 1988. Antipredator defenses and the persistence of amphibian larvae with fishes. *Ecology* **69:** 1865–870.

Leger Moss, J. T., 1988. A preliminary report for Queensland National Parks and Wildlife Service on the freshwater fishes of Morton Island, Queensland with special comment on the exotic "mosquito fish", *Gambusia affinis.* Dept. Recreation and Health: Brisbane City Council.

Littlejohn, M. J., 1968. Frogcalls and the species problem. *Aust. Zool.* **14:** 259–64.

Lloyd, L. N., Arthington, A. H. and Milton, D. A., 1986. The mosquitofish — a valuable mosquito-control agent or a pest? Pp. 7–25 in *The Ecology of Exotic Animals and Plants: some Australian case histories* ed by R. L. Kitching. John Wiley and Sons: Gladesville.

Lloyd, L., 1989. Ecological interactions of *Gambusia holbrooki* with Australian native fishes. Pp. 94–97 in *Introduced and Translocated fishes and their ecological effects* ed by D. A. Pollard. Australian Government Publishing Service: Canberra.

Mahony, M. J., 1993. The status of frogs in Watagan Mountains area of the Central Coast of New South Wales. Pp. 257–64 in *Herpetology in Australia: A Diverse discipline* ed by D. Lunney and D. Ayers. Royal Zoological Society of New South Wales: Mosman.

Martin, G., 1990. Froggy Bottom. *Discover* **1990:** 36–37.

McDowall, R. M., 1980. *Freshwater Fishes of South-eastern Australia.* Reed Publishing: Terrey Hills.

Merrick, J. R. and Schmida, G. E., 1984. *Australian Freshwater Fishes: Biology and Management.* Griffin Press Ltd: Netley.

Morin, P. J., 1981. Predatory salamanders reverse the outcome of competition among three species of Anuran tadpoles. *Science* **212:** 1284–286.

Moyle, P. B. and Cech, J. J., 1982. *Fishes: An introduction to Ichthyology.* Prentice-Hall Inc: New Jersey.

Myers, G. S., 1965. *Gambusia,* the fish destroyer. *Aust. Zool.* **13:** 102.

Petranka, J. W., 1989. Response of toad tadpoles to conflicting chemical stimuli: Predator avoidance versus "optimal" foraging. *Herpetologica* **45:** 283–92.

Phillips, K., 1990. Where have all the frogs and toads gone? *BioScience* **40:** 422–24.

Resetarits, W. J., Wilbur, Jr. and H. M., 1989. Choice of Oviposition Site by Hyla Chrysoscelis: Role of Predators and Competitors. *Ecology* **70:** 220–28.

Richards, S. J. and Bull, C. M., 1990. Size-Limited Predation on Tadpoles of Three Australian Frogs. *Copeia* **1990:** 1041–046.

Robinson, L., 1991. *Field Guide to the Native Plants of Sydney.* Kangaroo Press: Kenthurst.

Robinson, M., 1993. *A Field Guide to Frogs of Australia.* Reed Publications: Chatswood.

Sainty, G. R. and Jacobs, S. W. L., 1981. *Waterplants of New South Wales.* C. C. Merritt Pty Ltd: Chiswick.

Semlitsch, R. D., 1993. Effects of different predators on the survival and development of tadpoles from the hybridogenetic *Rana esculenta* complex. *Oikos* **67:** 40–46.

Semlitsch, R. D. and Gibbons, J. W., 1988. Fish predation in size-structured populations of treefrog tadpoles. *Oecologica* **75:** 321–26.

Slater, K., 1978. Fauna:reptiles and amphibians. Pp. 80–86 in *Land use on the South Coast of New South Wales, Vol 2.* ed by R. H. Gunn. CSIRO: Melbourne.

Smith, D. C., 1983. Factors controlling tadpole populations of the Chorus Frog *(Pseudacris triseriata)* on Isle Royale, Michigan. *Ecology* **64:** 501–10.

Southwood, T. R. E., 1966. *Ecological Methods with particular reference to the study of insect populations.* Chapman Hall: London.

Travis, J., Keen, H. and Juilianna, J., 1985. The role of relative body size in a predator-prey relationship between dragonfly naiads and larval anurans. *Oikos* **45:** 59–65.

Tyler, M. J., 1991. Our vanishing frogs. *Habitat* **19:** 20–25.

Tyler, M. J., 1992. *Encyclopedia of Australian Animals: Frogs.* Angus and Robinson: Pymble.

Tyler, M. J. and Davis, M., 1985. The gastric brooding frog *Rheobatrachus silus.* Pp. 469–70 in *The Biology of Australian Frogs and Reptiles* ed by G. Grigg, R. Shine and H. Ehmann. Surrey Beatty & Sons: Chipping Norton.

Warner, S. C., Travis, J. and Dunson, W. A., 1993. Effect of pH on interspecific competition between two species of Hylid tadpoles. *Ecology* **74:** 183–94.

BOOK REVIEWS — BOOK REVIEWS

A Shadow and a Song — the struggle to save an endangered species by M. J. Walters (1992).
Chelsea Green Publishing Company.
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There are few taxa whose time and cause of demise can be accurately documented. It is of the nature of rare species that we know little about them when they are alive, and we may be uncertain for many years as to whether or not they are extinct. The death, in captivity, of the last of several species, has been recorded, examples include the passenger pigeon and the thylacine. To this list can be added the Dusky Seaside Sparrow *Ammodramus maritimus nigrescens*, the last known individual dying on June 16, 1987.

The causes of extinction are many and various, although ultimately most can be ascribed to the cupidity and stupidity of *Homo sapiens*. The Dusky Seaside Sparrow was a victim of the American way of life, being destroyed by the space race and real estate development with the last bird dying in Disney World.

Despite, or perhaps because of, being recognized as endangered, and thus subject to special protection by conservation agencies, extinction was not averted. The story of the decline of the Dusky Seaside Sparrow is an object lesson in how bureaucratic confusion and vacillation can undermine the most noble of objectives. With increasing concern for the survival of threatened species, and a burgeoning industry in the production of recovery plans, Walters' book should be required reading by all conservationists. The existence of legislation (in this case the US Endangered Species Act) and apparently appropriate mechanisms for conservation is no guarantee of successful outcomes. If there is a villain of the story it is the US Fish and Wildlife Service but Walters is at pains to emphasize that the agency did not act with malicious intent, rather the Dusky Seaside Sparrow fell victim to the prevailing corporate wisdom which arose out of the agency's history.

Some would argue that sad as the tale is, the loss of the Dusky Seaside Sparrow was of no great consequence as it was not a distinct species, and even its subspecific status within a difficult taxonomic complex could be doubted. This would be to miss the point; there is no evidence that even if it were a clearly distinct full species appropriate conservation measures would have been applied. In addition the current biodiversity paradigm rightly stresses the importance of conservation of genetic diversity; genotypes, regardless of whether they are afforded formal taxonomic status, are proper subjects for conservation management. However, the taxonomic distinctiveness of the Dusky Seaside Sparrow did, at the eleventh hour, become of great significance. With the population reduced to a handful of individuals, all male, the suggestion was made to crossbreed with females of a related subspecies and then backcross the offspring so as to conserve "almost pure" Dusky Seaside Sparrows (a similar strategy to that currently being implemented with the Norfolk Island Boobook Owl). Unfortunately the Fish and Wildlife Service could not decide whether this was permissible under the Endangered Species Act, and after a period of indecision and lost opportunity the agency washed its hands of the problem and transferred the surviving captive males to Disney World.